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Characteristics of storm cells observed by the first polarimetric C-band radar in Minas Gerais

Ana M. Gomes [(1)], Maria A. Lima [(1)], Gerhard Held [(1)], Cesar A. Beneti [(2)], Leonardo Calvetti[(2)] and Arthur C. de Paiva Neto [(3)]

(1) Bauru, SP, Brazil (ana@gheld.net.br)
(2) Sistema Meteorológico do Paraná, SIMEPAR, Curitiba, PR, Brazil (beneti@simepar.br)
(3) Centrais Elétricas de Minas Gerais, CEMIG, Belo Horizonte, MG, Brazil (arthur.paiva@cemig.com.br)

Introduction

Extreme events of precipitation over or near large urban areas can cause flooding, often resulting in inundation of floodplains when the flow exceeds the capacity of the natural drainage channel. The occupation of land within cities and changes made in the catchments aggravate the situation. The occurrence of heavy rains and subsequent flooding in the hydrological basin that affects Belo Horizonte and its surroundings during the annual rainy season was one of the main reasons that prompted the installation of a Doppler weather radar with polarimetric capability for monitoring, forecasting and warning of storms in this region, at the end of 2011. The radar is located 50 km west of Belo Horizonte and more details are provided in a companion paper (Held *et al*., 2015). The TITAN (Thunderstorm Identification, Tracking, Analysis and Nowcasting; Dixon and Wiener, 1993) software was implemented for processing of data collected by the C-band polarimetric Doppler radar.

Data and Methodology

The radar data, collected during the summer months, *viz.* from December to February 2014, was considered for the statistical analysis of the storm properties to characterize the convective activity during this period. In total, 72 days were included in the sample. However, the full rainy season extends from October to March. Furthermore, it should be noted, that the surface rainfall was above normal during December 2013, but well below normal for January and February 2014 (CPTEC, 2014). TITAN, in its archive mode, was deployed as an objective storm-tracking tool. The TITAN track properties form the basis for this study. The program routine Tracks2Ascii extracts the radar data for each storm track for the specified period, if a radar echo exceeds the reflectivity threshold of 40 dBZ and volume threshold of 50 km^3 for at least two volume scans (15 minutes). For all storms that meet the criteria, their properties, such as height, volume, area, intensity, velocity and direction, were determined monthly within the aforementioned period. A performance assessment of TITAN is also presented for the selected period.

Analysis and Results

Volume and Horizontal Dimension of Radar Echoes

The frequency distribution for the average storm volumes, as seen in Figure 1, confirms the predominance of small, isolated storm types. The maximum average volume of storm cells varies between 169,3 and 198,5 km^3, and in 90% of storms it is less than 400 km^3, indicating that small cells predominate while volumes attain large values during these three summer months, in the Minas Gerais (MG) state. The majority of storms, occurring during that period, was entirely convective in nature, with areas ≤10^2 km^2 and only about 16% of the observed echoes accounted for larger ones, ranging from 10^2 – 10^3 km^2, most probably growing by merging processes. The presence of larger echoes, ranging from 10^3–10^4 km^2 in area, accounted for only 0,2% of the analyzed period.

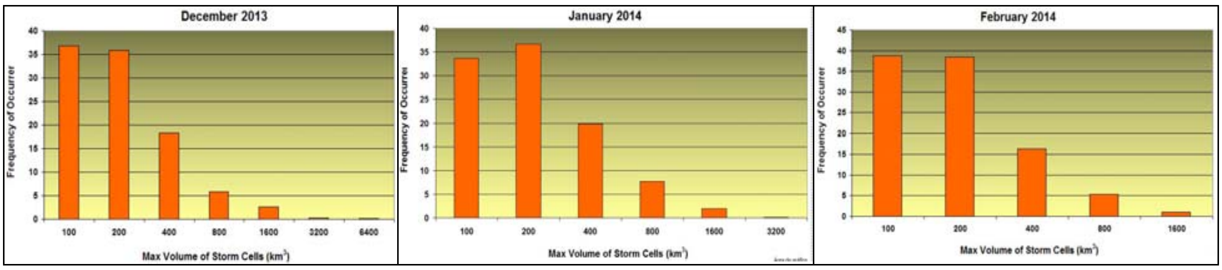

Figure 1. Relative frequency distribution of storm volumes observed by the CEMIG radar during the summer months from December to February.

No storms with a volume of less than 50 km^3 were recorded, due to the initially set threshold for the storm volume, which is one of the parameters applied to identify storm cells.

Height of Storm Echoes

Echo height is a good indicator of storm development and severity. A relative frequency distribution of maximum heights of the 10 dBZ contour of the cells is presented in Figure 2, for the three summer months.

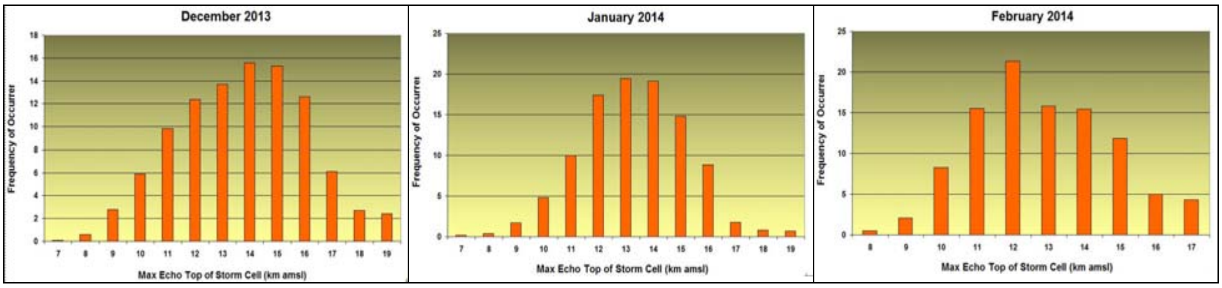

Figure 2. Relative frequency distribution of the maximum cell height (10 dBZ), for the storms observed by the CEMIG radar during the summer months.

The mean value of maximum echo height was 12,8 ± 2,2 km amsl (above mean sea level) and about 71% of the observed storms reached heights of between 12 and 13 km amsl, dropping off drastically towards the higher values, with only about 12,9% of the observed storms extending to heights between 16 and 17 km amsl. It should be noted here, that for case studies of severe storms, the term "echo top" usually refers to the maximum height of the 15 or 10 dBZ reflectivity contours, but in this analysis the 10 dBZ threshold was chosen to delineate the top of the storm cells. The average maximum echo tops for the threshold of 40 dBZ were around 7 km or less, with a frequency of 65% of the time.

Duration of Storm Echoes

Each radar echo was identified and tracked by TITAN throughout its lifetime, based on the selected threshold. Similar to the area, volume, and echo height characteristics, this method also yielded the frequency distribution of the echo storm duration for the study period. Figure 3 shows that the majority of storms, which occurred during this period, was of short duration, *viz*., predominantly less than 1 hour (68%) and associated with echoes from the D scale (Houze and Cheng, 1977) or isolated type of convective storms.

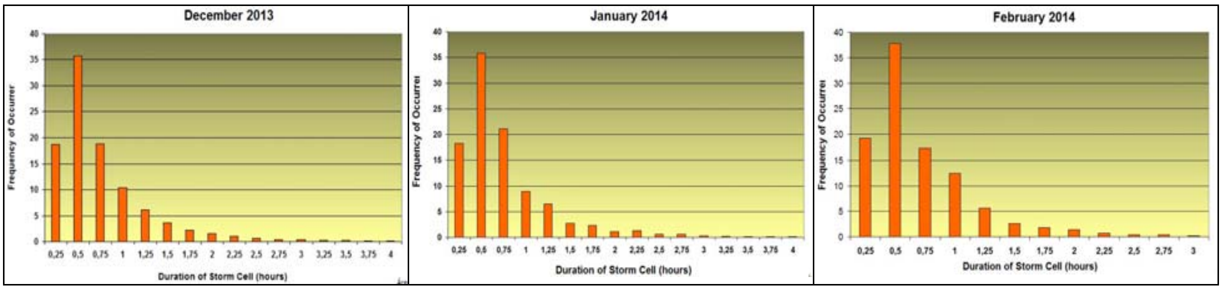

Figure 3. Relative frequency distribution of the duration of storm echoes as observed by the CEMIG radar during the summer months.

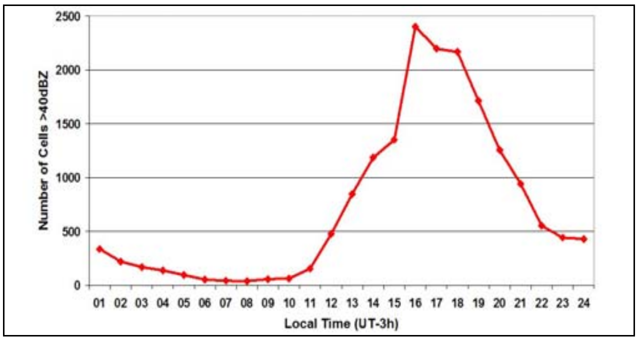

Figure 4. Diurnal variation of the number of cells with >40 dBZ as observed by the CEMIG radar during the summer months from December 2013 to February 2014.

To determine the diurnal variability of convection, storm cells with a reflectivity threshold of >40 dBZ were identified by TITAN and classified into hourly intervals. The frequency distribution in Figure 4 indicates the afternoon as the preferred time for intensification, with a maximum at around 16:00 LT (Local Time = 19UT), when the largest number of storms were identified by TITAN. Earlier studies of the diurnal cycle of heavy rains in the Metropolitan Region of Belo Horizonte, using data from a conventional rain gauge network, confirm these results (Munt and Raia, 2010).

Storm Velocity and Direction of Movement

The frequency distribution of storm velocity and preferential direction of storm movement was also determined for the study period. The results are summarized in Figures 5 and 6. They highlight that during the period, the average velocity of 83% of the observed storms varied from 5 to 20 km.h^{-1}, while the remaining 27% had speeds of between 25 and 55 km.h^{-1}. The overall average speed of cell displacement was 15 km.h^{-1}, but during December 2013, speeds of >10 km.h^{-1} were significantly more frequent than during the two subsequent months. The preferential direction of movement was from the northwest sector during December 2013, due to the persistence of a South Atlantic Convergence Zone (SACZ; CPTEC, 2014; Held *et al.*, 2015), while in January 2014 the storms moved more or less in all directions, but with a prevalence for easterly directions towards the western sector. In February 2014, a dominant movement of storms was observed from north to south, with the remainder having directions into the western sector (SSW – WNW). During both months, the storm directions were more variable due to the South Atlantic Ocean Anticyclone extending over the region in the mid-levels (500 hPa) with an extremely weak gradient, not facilitating any synoptic forcing (CPTEC, 2014).

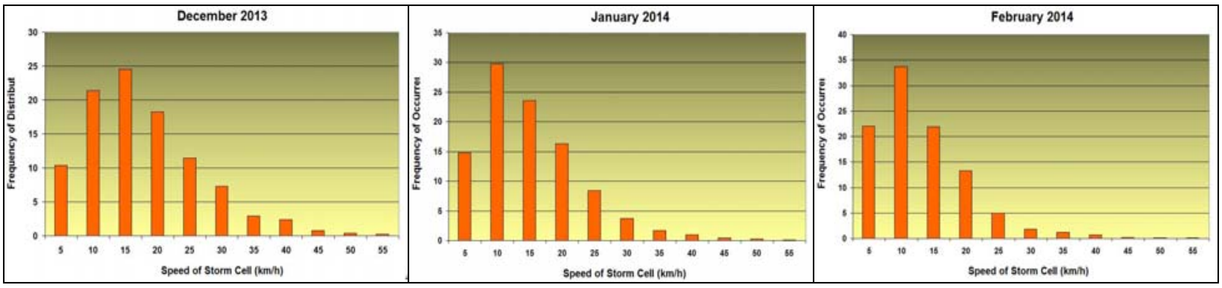

Figure 5. Relative frequency distribution of the speed of storm cells as observed by the CEMIG radar during the summer months.

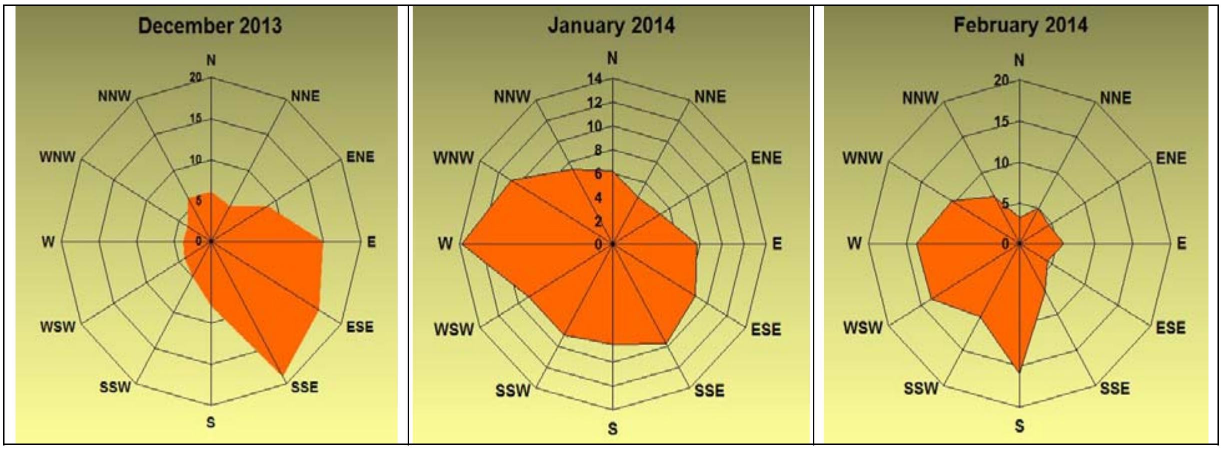

Figure 6. Frequency distribution of the preferential direction (towards) of movement of storm echoes as observed by the CEMIG radar during the summer months.

TITAN Performance Assessment

The evaluation of the TITAN performance to identify, track and forecast storms within the radar range of 250km, during the period analyzed, was based on a comparison of predicted and observed results from several thunderstorm processes, by calculating three parameters as an evaluation index: Probability of Detection (POD), False Alarm Rate (FAR) and CSI (Critical Success Index; also called “Threat Score (TS)”). The performance of TITAN in identifying potential storms by tracking all cells that met the adopted criteria for the selected thresholds have shown good results up to a forecasting interval of 30 minutes, but is rapidly degrading when the forecast lead time increases to 60 minutes, as can be seen in Figure 7. The average CSI values for all three months diminish from 0,5 to 0,3 for forecast lead-times from 15 to 60 minutes. Similarly, the average FAR increases from 0,4 to 0,6, while the average POD ranges from 0,77 to 0,67.

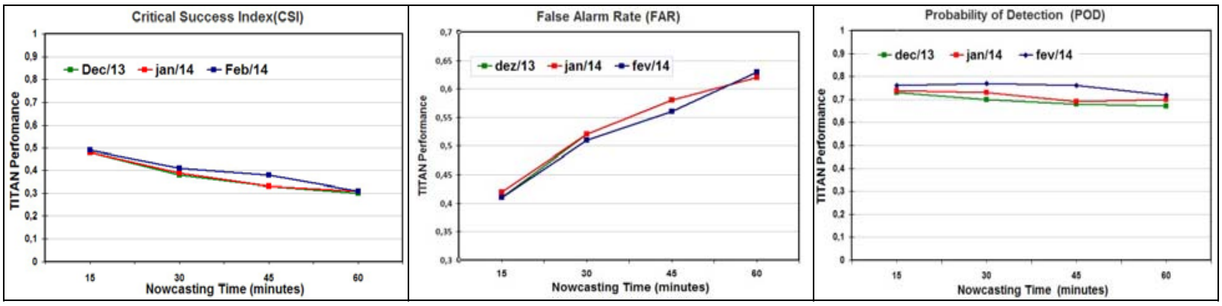

Figure 7. TITAN average performance indices CSI, FAR and POD for forecasting lead times from 15 up to 60 min. (The values of CSI and FAR for December and January are almost coincident, resulting in overlapping lines).

Conclusions

The deployment of the TITAN software allowed for the first time to quantify various properties for storms observed in the Minas Gerais state by the radar system, recently acquired by CEMIG, and installed at Elephant Hill of the Matheus Leme mountain range.

Analysis has shown, that during the three summer months (December 2013 to February 2014), a large percentage of the storms was small, with a mean volume of less than 200 km^3 and a duration of less than 1 hour, indicating a predominantly isolated convective activity, typical for a relative dry summer season in the southeastern region of Brazil. This is also confirmed by the anomaly rainfall maps, showing above normal rainfall during December 2013, but below normal for January and February 2014. As expected, convective activity peaked at around 16:00 LT (19UT), when the largest number of storms were identified by TITAN. The mean maximum cell height was 12,8 ± 2,2 km amsl, for all storms identified by using a reflectivity threshold of 10 dBZ, with some tops reaching up to 17-18 km height during this period. The distribution of storm velocities and direction of preferential movement was from the northwest sector during December 2013, while in January 2014 the storms moved more or less in all directions, but with prevalence for easterly directions towards the western sector. In February 2014, a dominant movement of storms was observed from north to south, with the remainder having directions into the western sector (SSW – WNW). Velocities ranged from 5 to 55 $km.h^{-1}$ with an average speed of 15 $km.h^{-1}$.

Acknowledgements

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